

V. L. Bondarenko, Yu. M. Simonenko

# CRYOGENIC TECHNOLOGIES OF RARE GASES EXTRACTION

621.59  
15 81

621.592 + 661.9

UDK 661.939:621.59

BBK 35.263

B81

V. L. Bondarenko, Yu. M. Simonenko

# CRYOGENIC TECHNOLOGIES OF RARE GASES EXTRACTION

Monograph

Odessa  
"Astroprint"  
2014

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The monograph is recommended for publication by the Academic Council of the Odessa National Academy of Food Technologies. (*Minutes #12 from 02/06/2013*)

**Bondarenko V. L.**

B81 Cryogenic Technologies of Rare Gases Extraction : monograph / V. L. Bondarenko, Yu. M. Simonenko. — Odessa : Astroprint, 2014. — 312 p.

ISBN 978–966–190–834–4

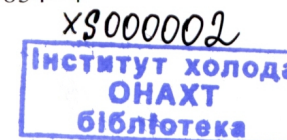
The monograph examines the physical basis of extraction of inert gases from air. It also describes methods of preparation of multicomponent mixtures. Separate chapters are dedicated to the processes of phase separation, adsorption and membrane separation.

It contains technological flow charts of the main stages of helium, neon, krypton, and xenon production. Examples of calculations for extraction, enrichment and purification of inert gases are given. There are reference data, schemes of laboratory stands and additional information in the supplements to the monograph.

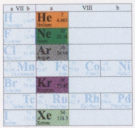



UDK 661.939:621.59  
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ISBN 978–966–190–834–4

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## TABLE OF CONTENTS

FOREWORD .....	9
INTRODUCTION .....	10
 1. INERT ("RARE" and "NOBLE") GASES .....	12
1.1. Sources of Rare Gases .....	13
1.2. Properties of Air Components .....	15
1.3. Application Fields of Rare Gases .....	16
 2. IDEAL GAS LAWS AND FUNDAMENTAL PROCESSES ...	26
2.1. Isochoric Process .....	26
2.2. Isobaric Process .....	29
2.3. Isothermal Process .....	31
2.4. Equation of State for Ideal Gas .....	34
2.5. Avogadro Law .....	38
 3. GAS MIXTURES .....	45
3.1. Physical Basis of Mixing Substances ...	45
3.2. Obtain of Mixtures in the Form of Condensed Gas .....	50
3.3. Laboratory Ways of Mixing Gases .....	55
3.4. Alteration of Gas Mixture Concentration in the Unit .....	60
 4. REAL GASES AND GAS MIXTURES ...	67
4.1. Compressibility .....	67
4.2. Phase Change Vapour-Liquid in Pure Substances .....	72

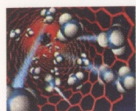
4.3. Phase Equilibrium .....	75
4.4. Humid Air .....	79
4.5. Equilibrium States in Binary Mixtures ..	82
4.6. Diagrams of Binary Mixture State Parameters .....	89



5. PROCESSES AND DEVICES FOR GAS MIXTURE SEPARATION BY CONDENSATION METHODS .....	95
5.1. Continuous Condensation of a Binary Mixture in a Phase Separator .....	95
5.2. Design and Operation Principle of a Reflux Condenser .....	100
5.3. Continuous Rectification of Binary Mixtures .....	104
5.4. Types of Rectification Devices and Design Principles .....	107



6. APPLICATION OF ADSORPTION TECHNOLOGIES IN CRYOGENICS ...	142
6.1. Process Essence and Sorbent Types ...	142
6.2. Theoretical Grounds of Adsorption of Pure Substance .....	144
6.3. Adsorption of Multicomponent Mixtures .....	151
6.4. Periodical Sorption Processes in a Single Unit .....	154
6.5. Organisation of Continuous Purification of the Stream .....	158
6.6. Design of Adsorption Purification Blocks .....	162



7. MEMBRANE SEPARATION OF A GAS MIXTURE ..... 167

7.1. General Concept of Membrane Processes ..... 167

7.2. Physical Basis for the Baromembrane Separation of a Binary Mixture ..... 170

7.3. Modeling Technique for the Membrane Separation of the Mixture Ne-He-N<sub>2</sub> .. 179



8. TECHNOLOGICAL SUCCESSION OF NEON AND HELIUM PRODUCTION ..... 186

8.1. Extraction and Primary Enrichment of Concentrates ..... 186

8.2. Final Purification of Ne-He Mixture ... 190

8.3. Separation of Neon-Helium Mixture by Rectification Method ..... 194

8.4. Technological Sequence of Producing Light Inert Gases ..... 199



9. TECHNOLOGIES OF KRYPTON AND XENON PRODUCTION ..... 205

9.2. Classical Technology of Primary Concentration ..... 206

9.3. Secondary Enrichment of the Product by Rectification Method ..... 209

9.3. Adsorption Technologies of Krypton and Xenon Extraction ..... 213

9.4. Peculiarities of Producing Pure Krypton and Xenon ..... 217

REFERENCES ..... 221

## SUPPLEMENTS

1. INERT ("RARE" and "NOBLE") GASES

1.1. First Acquaintance with Inert Gases ... 226

1.2. D. I. Mendeleev's Periodic Table (Natural System) of Elements ..... 229

1.3. A Surprising Fate of Simple Discovery ... 230

1.4. Brief Knowledge of Stable Gas Isotopes ... 234

2. IDEAL GAS LAWS and FUNDAMENTAL PROCESSES

2.1. Physical Quantities and Instruments ... 236

2.2. Gasholders Design ..... 240

3. GAS MIXTURES

3.1. Thermophysical Properties of Gas Mixture Components ..... 242

3.2. Acquisition of Gas Mixtures in Continuous Dosing Devices ..... 245

4. REAL GASES and GAS MIXTURES

4.1. Compressibility Diagram ..... 250

4.2. *P-T* Diagrams of Pure Substances ..... 251

4.3. Data of Temperatures and Saturation Pressures of Some Gases Forming Atmosphere ..... 253

4.4. Humid Air ..... 255

4.5. Equilibrium States for Real Binary Mixtures ..... 260

5. PROCESSES AND DEVICES FOR GAS MIXTURE SEPARATION BY CONDENSATION METHODS

5.1. Production of Concentrates of Ethyl Alcohol ..... 264

5.2. Calculation Example of a Number of Transfer Units in a Rectifying Column .....	272
<b>6. APPLICATION OF ADSORPTION TECHNOLOGIES IN CRYOGENICS</b>	
6.1. Popularly — What the Adsorption is ...	282
6.2. Regeneration of Sorbents .....	284
<b>7. MEMBRANE SEPARATION OF A GAS MIXTURE</b>	
7.1. Universal Calculation Method for a Membrane Separation of a Multicomponent Mixture .....	286
7.2. Membrane Systems with Recirculation of Streams .....	291
<b>8. TECHNOLOGICAL SUCCESSION OF NEON AND HELIUM PRODUCTION</b>	
8.1. “PPB” and “PPM” .....	293
8.2. To Laboratory Work “Enrichment of Neon-Helium Mixture Due to Nitrogen Condensation in Reflux Condenser at $T = 66...78\text{ K}$ ” .....	295
8.3. To Laboratory Work “Enrichment of Neon-Helium Mixture in Adsorber at $T = 78\text{ K}$ ” .....	298
<b>9. TECHNOLOGIES OF KRYPTON AND XENON PRODUCTION</b>	
9.1. Control and Safety Valves .....	301

## FOREWORD

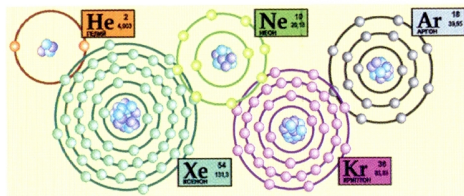
The book covers the most important field of cryogenics, i. e. separation of gas mixtures.

One way or another, the emergence and development of cryogenics was connected with the liquefaction of more and more gases, including the atmospheric air components. The unique experiments made in the low temperature laboratories were later used as the basis for the development of new industrial technologies. At the beginning of the 20<sup>th</sup> century, it became clear that the extraction of oxygen, argon and other gases from atmosphere by cryogenic methods was not only technologically feasible, but also economically viable. Metallurgy, lighting, and chemistry could not develop without new products extracted at low-temperature facilities. During the next decades, the “gas mission” of cryogenics was extended even further. Industrial and rare gases consumption is growing annually in various fields, from medicine to space technology.

In spite of the importance of cryogenics, the publication of a new textbook or a reference book is not a frequent event in this field. The latest research results are mostly dispersed over various journals, and they are often “islands” of isolated information that is not easily applicable in practice.

The authors of the monograph have made an attempt to organise separate pieces of existing knowledge and present them in a clear logical sequence, so that every new part is based on the studied (well known) information and supported by illustrative material.

A special feature of the monograph is its close connection with adjacent sciences, including both fundamental disciplines (chemistry, physics, and thermodynamics), and practical fields (industrial adsorption, chemical production, gas chromatography, etc.). Such a combination of the fundamental and specialised knowledge in one monograph allows us to recommend it to a wide circle of readers who wish to get an insight into the new achievements of cryogenics.



## INTRODUCTION

This millennium mankind is facing a problem of exhaustion of our planet's natural resources. The developed countries allot more and more of their financial, scientific and industrial potential to providing themselves with energy and raw materials. The materials which, until the past century, were available virtually on the surface of the Earth are now extracted from either deep wells and mines, or great ocean depths. People will have to seek some chemical elements outside our planet already in the 21<sup>st</sup> century. However, we seldom think that the surrounding atmosphere, besides oxygen and nitrogen, offers really valuable products, namely, inert gases.

At the end of the 19<sup>th</sup> century, scientists believed they knew everything about the surrounding world. At that time, when the air composition was considered to be fully known, and the presence of new elements in it seemed impossible, W. Ramsay was awarded (in 1904) the Nobel Prize in chemistry. The award citation listed his discovery as confirming presence of several **inert gases** in the atmosphere and their correct placement in the Periodic table of chemical elements. Ramsay's finding of the family of noble "brothers" — **argon**, **helium**, **neon**, **krypton** and **xenon** — occurred at the time when the Periodic table seemed to be completed, and there were almost no empty cells in it. (Such unique incomplete versions of the table are now available in Moscow Polytechnical Museum). D.I. Mendeleev and W. Ramsay met in London in March 1900, and then it was officially decided to include a new group of chemical elements into the Periodic table.

Besides the listed gases, **radon** (Rn) and **ununoctium** (Uuo) have been attributed to the VIII group of the periodic table as well — see Supplements 1.1, 1.2. The latter element was discovered by Russian and American scientists only in 2006. Like radon, Uuo is a radioactive element, and no practical application has been found.

The VIII group of elements owes its name to the common feature of its elements — their inertness to chemical reactions with other elements. This low chemical activity of inert gases is explained by their electronic structure (their external (valent) electron shells are completely filled). Inert gases are colourless, odourless and non-toxic. Actual indifference to other elements and chemical compounds complicates the practical separation of the mixtures containing these gases.

This book is devoted to the analysis of different methods of extraction and production of pure inert gases. The authors have made an attempt to present the physical essence and technological methods of gas mixture separation in a clear logical order. Many specific examples have been added to the monograph in order to facilitate understanding and practical use of the materials.